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Theoretical Study for Effect Temperature on Fractal Optical Modulator by Using Modulation Transfer Function

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Abstract

Optical modulator or chopper is an important part in an optical system. It is a device, which changes the angle between the vision line of the target and coordinate to an electrical signal. This paper has been designed as a new model of the fractal optical modulator. A new optical modulator involves two cycles (inner and outer). Each cycle of them consists of eighteen sections. Any designer may be known that the sections of the optical modulator become two parts, nine sections consider is transparent and other section nine is opaque to light. There are two parameters have taken to design the optical modulator, first factor is the shape and second factor is the section number. A new chopper is made from semiconductor material such as Cadmium Telluride by using the fractal function. A chopper is created by building a computer program using the visual basic language. For the importance of the modulation transfer function in testing and evaluating optical systems, it becomes the dependent measurement to know the optical systems efficiency. It has been studied for optical systems with a circular aperture, where that function could evaluate the image efficiency for point object of image plane at different magnitude of the temperature and wavelengths. In this research, the fractal optical modulator has been designed of semiconductor material by using the fractal function. Then evaluating the values of MTF at different values of the wavelength and temperatures. Also, we studied the relation between spatial frequency and MTF.

Keywords: Chopper; optical modulator; fractal; MTF; spatial frequency.

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1. Introduction

Cadmium telluride (CdTe) thin films are prepared by several methods such as physical vapour deposition technique [1], and the dip-coating deposition technique under atmospheric pressure at different temperature. Films are good photoconductive in nature and could be used in photovoltaic applications [2, 3]. From the chalcogenide semiconductor class, cadmium telluride is of continuing promising contenders for use in a large scale for novel devices technology (i.e. solar cells, field effect transistors, IR and γ detectors, etc.) [2]. Cadmium telluride has “proven to provide a good optical performance across a wide range of temperatures and has provided adequate mechanical robustness to be used as a substrate material. Cadmium telluride has a high resistance to moisture sensitivity, is available at a reasonable price and can operate at elevated filter deposition temperatures without disassociating” [4].

Usually the optical system has passed through several steps into production. The optical design is the first step, after this stage is completed. The optical components manufacturing will be the next stage. Finally, the calculation and the testing of these components are the last steps. The optical design includes specifications for the radii of the surface curvature, the thickness, and the air spaces, the diameters of the various components, the type of glass to be used and the position of the stop. These parameters are well-known as "degrees of freedom" since the designer can change them to maintain the desired system. The image that is formed by these optical systems will approximately correct from the aberrations. But, there isn't an ideal image which corresponds to the dimensions of the object because of the wave nature of the light, which is most affected by several factors like the type of illumination that is used (coherent, incoherent, and partially coherent), the object shape (Point, Edge or Line) and the aperture shape[5]. Optical modulator any device used to modify any characteristic of an optical signal (light wave) for the purpose of conveying information. Optical reticle (modulator) are mechanical devices that physically block a light beam of some type. Rotating optical modulators (choppers) are perhaps the most common form and are they produced by SciTech Instrument Ltd. A metal disc with slots etched into its mounted on a dc motor and rotated. The disc is placed in the light beam path which will then cause the beam to be periodically interrupted by the blocking part of the disc [6].

The word fractal was coined in 1975 by Benoit Mandelbrot, from the Latin fractious, meaning "broken" or "fractured" The word fractal has two related means. In colloquial usage, it denotes a shape that is recursively constructed or self-similar, that is a shape that shows similar at all scales of magnification and is therefore often indicated to as "infinitely complex". The fractal in mathematics is a geometric object that satisfies a specific technical condition, namely having a Hausdroff dimension greater than is topological dimensions [7].

1.1. Optical Modulator

Optical modulator or chopper is a device, which changes the angle between the vision line of the target and coordinate to electrical signal [7]. An optical modulator is used to provide directional information about the target , and to suppress unwanted signals from background[5]. It is a device used for chopping the emitted light from the source. This will be done by choosing the best shape and size. The optical modulator takes many various circular shapes due to its need [6].

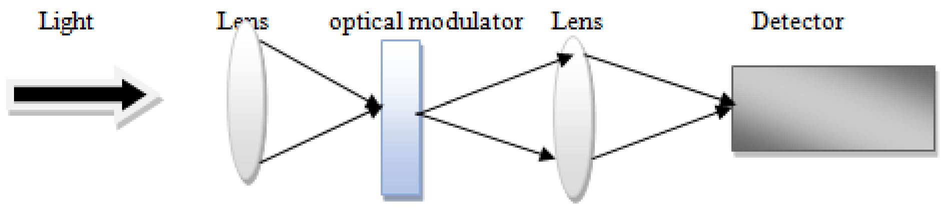


Figure 1: The Position of the modulator in the optical system.

The optical modulator is called in many different names: optical modulator, chopper, raster, reticle and crosshair (in special cases).

The term reticle has been defined as "a pattern located in the focal plane of an instrument to measure or locate a point in an image". Reticle has been used and is still used in a multitude of operations from commercial applications or surveying to military uses of boresighting surveillance and fire control systems. The general case that most people is familiar with is the simple sight on a rifle or gun. There are as many types of reticle as there are uses for them. However, one type of reticle, commonly referred to as a spinning frequency modulated (FM) reticle, can be used to provide range and bearing information [8].

The word reticle is from the Latin which means (net) a network or grid of lines displayed in an optical instrument. The minimum reticle consist of simple "cross-hairs"[9], a crosshair is a shape superimposed on an image that are used for a device precise alignment. Crosshairs are most commonly a "+" shape, although many variations exist, including dots, spots, circles and chevrons. Most commonly associated with telescope sights for aiming firearms, crosshairs are also common to optical instruments used for astronomy and surveying and also popular with graphical user interfaces as a precision pointer. It is sometimes called the chopper. i.e. the optical modulator is a device used for chopping the light beam and the output signal has frequency which can be described by this relation:

$$F = n * v \qquad (1)$$

Where: n: number of sectors, v: the velocity of angular (rotation speed), F: the spatial frequency.

The modulation operation in optical modulator depends on the movement between image object and optical modulator. In this concept the optical modulator can be classified in two types: -

1-Rotating Reticle Disk: In this type, the disk rotates around its axis, while the object images rotate within the disk area. Sometimes, the disk axis has been rotated around the optical axis of the Electro-Optical-System, in circular path. This type of disk is called (Nutating Reticle).

2-Stationary Reticle Disk: In the second type of this disk is stationary, while the image object has been rotated on the disk surface by using rotational optical system.

The optical modulator has two important operations in detection, tracking and guidance system, and this operation are to:-

1-Provide directional information about tracking and to suppress unwanted signals from the background. This operation is called (Spatial-Filtering).

2-Change the optical signal parameter, which is produced from the object, by designing suitable disk pattern.

The modulation can be done by using two types of mode Active and Passive modes. The two operations can be applied in the active mode at the same time, while just the second operation can be applied in the passive mode.

The better efficiency of the optical modulator can be produced when the spot size is not larger than three times the object image size. The real efficiency is produced when the spot size is equal to the object image. When the object image approaches the optical system, its size will be increased.[5,9]

1.2. AM and FM Optical Modulator

One of the optical modulator shapes is (Fan Shape), and sometimes called (Wagon Wheel), it is shown in Fig.(2) and it is used in many optical applications, In radiation measurement system, it is used as optical chopper**.** Therefore, it is used in optical modulation in most Tracking and Guidance systems.

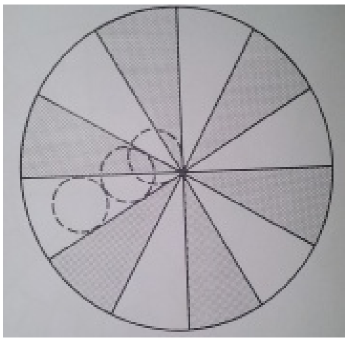


Figure 2: wagonwheel patter

This type of optical modulator works in two modes:

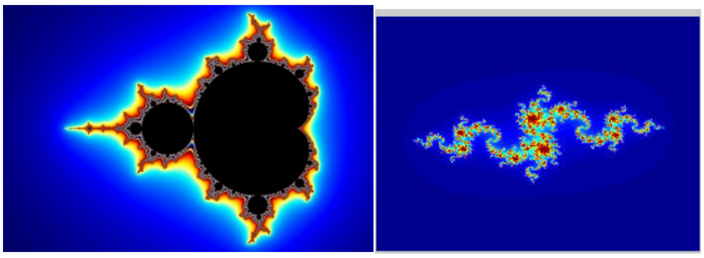
first mode, is when the optical modulator is rotated around its axis. Then, the incident radiation will be modulated in amplitude modulation (**AM)** .

The second mode, is when the optical modulator is stationary, while the object scene rotates about the disk axis by nutating movement. Or the optical modulator center will be rotated about the optical axis of the tracking system. then the incident radiation will be modulated in frequency modulation (**FM)** [10,11].

1.3. Fractal Function

Euclidean geometry provides a first approximation to the structure of physical objects. It describes objects of simple shapes, point, line segments, ellipses, circles, boxes, and cubes that have a few characteristic sizes, with dimensions one, two, and three. This geometry is mainly oriented a round linear, integral system[12]. Nonlinear shapes and nonintegral systems are not easily described by the traditional Euclidean geometry. These shapes and systems need another geometry that is quite different from Euclidean geometry to describe and study these cases. Benoit Mandebort [13] suggested the existence of geometries near to the geometry of nature, known as fractal geometry. Mandelbort, coined the term "Fractal" to describe object that is very "fractured" as a clouds, mountains, coastlines, leaves, sun,...........etc.

Mandelbrot's famous and pioneering work with fractal geometry and his introduction to two new basic concepts including; first, self-similarity, which is to say that the fractal shapes are to be self-similar and independent of scales or scale. The general nature of the fractal irregular bumpy structure remain constant through successive magnifications such as is the case for coastlines and mountains. Each small portion when magnified can reproduce exactly a large portion. Fractal images to exists as the limit of both random and deterministic processes based upon the representation named Iterated Function System (IFS). Second, a fractal has non-integer dimension known as the fractal dimension, which allows scale independent measurement of such objects, and gives a numerical measure of the degree of boundary irregularity or surface roughness. The fractal dimensions one of the most important concepts in the study distribution. It is analogous to the concepts of length, area and volume in Euclidean Geometry [14] And from examples of nonlinear fractals: Mandelbrot set, and Julia set which they are shown in fig. (3).



(a)-Mandelbrot set (b)- Julia set

Figure 3: Mandelbort and Julia sets

Now it is seen an alternative way to specify the dimension of a self-similar object. The dimension is simply the exponent of the number of self-similar pieces with magnification factor N into which the figure may be broken.

$$N = \left(\frac{L}{K}\right)^{D'} \qquad (2)$$

$$D' = \frac{\log N}{\log\left(\frac{L}{K}\right)} \qquad (3)$$

Where $D^{\backslash}$ is fractal dimension, N: number segment, L: length, K: length each piece.

1.4. Iterated function system (IFS)

Fractals as they are normally called can be any number of dimensions, but are commonly computed and drawn in 2D. The fractal is made up of the union of several copies of itself, each copy being transformed by a function. This is the source of its self-similar fractal nature[15] Formally,

$$s = \cup_i f_{i\,(s)} \qquad {}_{where\ s \subset R^2}\ and\ f_i: R^2 \rightarrow R^2 \qquad (4)$$

And (i=1, 2, 3, 4……..m).

Sometimes each function f_i is required to be linear, or more accurately an affine transformation and hence can be represented by a matrix.

$$W\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} \qquad (5)$$

$$w\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} ax + by + e \\ cx + dy + f \end{bmatrix} \qquad (6)$$

Where (x, y): a metric space, (e, f): transformation parameters and (a, b, c, d): real numbers (in two-dimensional)

However, IFSs may also be built from non-line a function, including projective transformations. One can describe a general construction for fractal that occurs in classical number theory, of which sierpinski triangle, von koch curve, and cantor set are examples.

1.5. Cantor Set

In order to understand the cantor set, the construction becomes with a line segment of length (1) which is subdivided into three sections, removing the middle third; then removing the middle third of the remaining segment and so on. So, the number of segments is increased to two and length is reduced to (2/3). The cantor set is simply the dust of pointing remain. The number of these points is infinite, but their total length is zero. As shown in figure(4) [16].

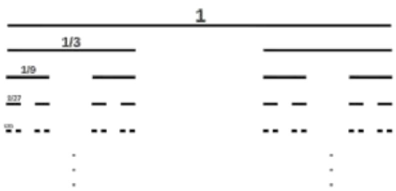


Figure 4: Construction of the classical cantor set

1.6. OTF & MTF

Another method to specify the resolving power of an optical imaging system is by means of the optical transfer function (OTF). This function is defined as the contrast in the image of a sinusoidal grating with a given spatial frequency,

$$w = \frac{2\pi}{L} \qquad (7)$$

Let us assume that we form the image of an object containing a wide spectrum of spatial frequencies. Then analyze the frequency content of the image of this object. Then, the OTF is the ratio of the amplitude of a given spatial frequency in the image to the amplitude of the component with the same spatial frequency in the object. If the object contains all spatial frequencies of a constant amplitude, the OTF becomes the Fourier transforms into the image. Such an object is the point object and its image is point spread function (PSF). Hence, the OTF is simply the Fourier transforms from the point spread function. the optical transfer function $F(\omega_x, \omega_y)$ may be obtained from the Fourier transform of the point spread function S(x,y) as follows:

$$F(w_x , w_y) = \iint S(X_F, Y_F)\, e^{i(w_x X_F , w_y Y_F)} dx_F dy_F \qquad (8)$$

We see that in general this OTF is complex and, thus it has a real and an imaginary term. The modulus of the OTF refer to the modulation transfer function (MTF) and represents the contrast in the image of a sinusoidal periodic structure. The imaginary term receives the name of phase transfer function (PTF) and gives information about the spatial phase shifting or any contrast reversal (when the phase shift is 180^o) in the image. [17]

The MTF is then the magnitude response for the imaging system to sinusoids of different spatial frequencies. This response can also be defined as the attenuation factor in modulation depth:

$$M = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \qquad (9)$$

where Amax and Amin denote to the maximum and minimum values of the waveform that describe the object or image in W/cm^2 versus position. The modulation depth is actually a measure of visibility or contrast. The effect of the finite-size impulse response (this mean that not a delta function) of the optical system is to decrease the modulation depth of the image relative to that in the object distribution. This attenuation in modulation depth is a position function in the image plane. The MTF is the ratio of image-to-object modulation depth as a function of spatial frequency:[18]

$$MTF = \frac{M_{img}}{M_{obj}} \qquad (10)$$

or

$$MTF = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad (11)$$

In summary, the MTF is a powerful tool used to characterize the imaging system's ability to reproduce signals as a function of spatial frequency. It is a fundamental parameter that determines where the performance limitations in optical and electro-optical systems occur, and which crucial components must be enhanced to yield a better overall image quality. It guides system design, and predicts system Performance [18].

2. Discussion and result

The optical modulator is an important component in optical system. The optical modulator is a disc from semiconductor material which has a radius R_1 and R_2 where R_1 refer to the radius inner of the circle and R_2 indicate to the radius outer of the circle, and assumes the number of sectors is eighteen sectors. The chopper is designed by the computer program, it was written by using visual basic language. In the present study assume that nine sectors opaque and other nine sectors are transmitted alternating to the light as shown in figure (5**).** Fractal function was used to divide optical modulator into very small segments of line, it's simply the dust of point (Cantor set). The circular aperture were a clear transparence aperture (100%).

Assume that the incident lights are a vertical to the chopper. The chopper is moving in a circular form. Hence, the light beam will make discrete circles according to the number of sectors. The distance from the light movement on all sectors of it is parting is an arc from the circumference of the total circle. Thus, the light form will through one revolution of the radius (the point of beam incidence of light on the sector). It is considered that the arc of a sector, which moves on the opaque sector are the required distance only. The resultant circumference of the circle was divided among the total number of sectors.

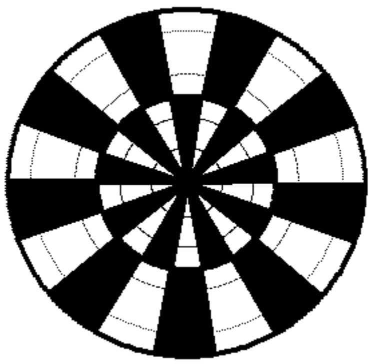


Figure 5: fractal optical modulator (design by searchers)

The unit of spatial frequency will be in (Rev/s) which depends on the velocity, and the number of sectors. Equations 1 and 11 have been simulated utilizing visual basic environment in order to obtain values of MTF and spatial frequency. The result of these equations has been plotted as shown in figures (6-11). The obtained behavior in these figures is agreement with the other published paper [19]. Figures (6-11) show the behavior modulation transfer function (MTF) with spatial frequency of various temperatures of Cadmium Telluride (CdTe). All figures to reveal that the MTF is decreasing by increasing the spatial frequency when the same temperature is used. The spatial frequency is very small at the maximum value of MTF, and the spatial frequency begins increase with decreasing of MTF values.

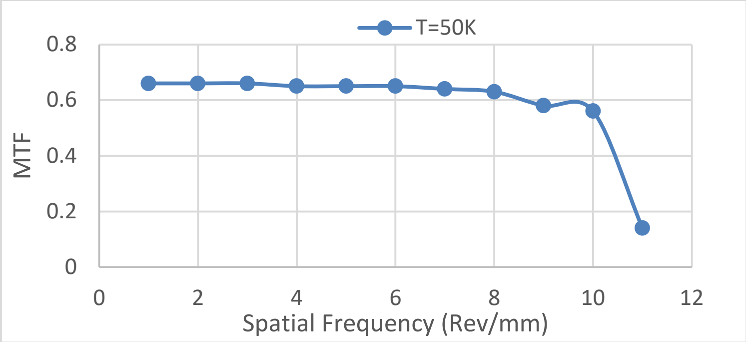


Figure 6: spatial frequency versus MTF at temperature (50 k)

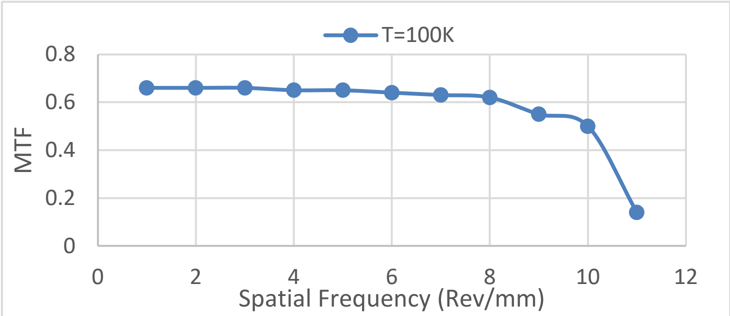


Figure 7: spatial frequency versus MTF at temperature (100 k)

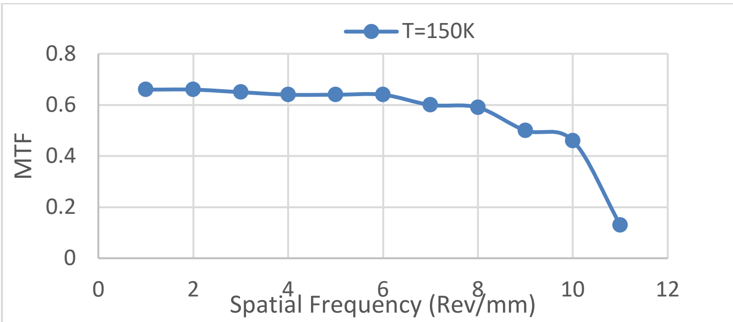


Figure 8: spatial frequency versus MTF at temperature (150 k)

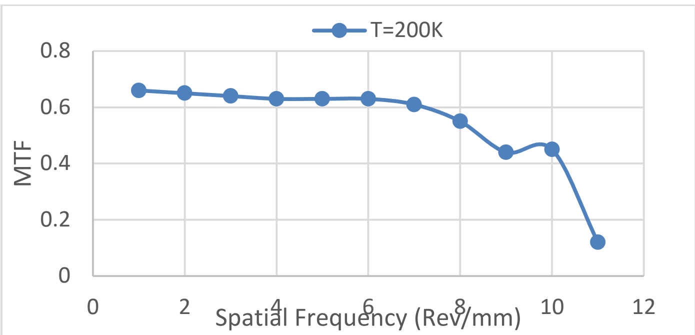


Figure 9: spatial frequency versus MTF at temperature (200 k)

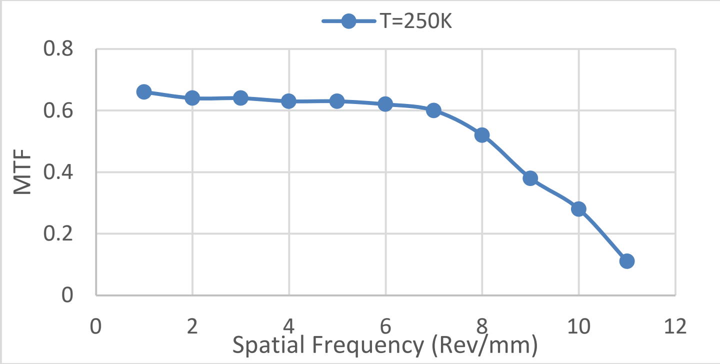


Figure 10: spatial frequency versus MTF at temperature (250 k)

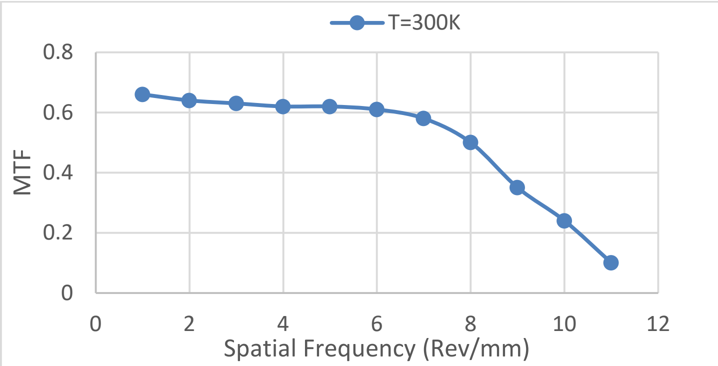


Figure 11: spatial frequency versus MTF at temperature (300 k)

Figure (12) shows the behavior modulation transfer function (MTF) with wave lengths of various temperature of CdTe. All curves to reveal that the MTF is decreasing by increasing the temperatures when the same wavelength is used.

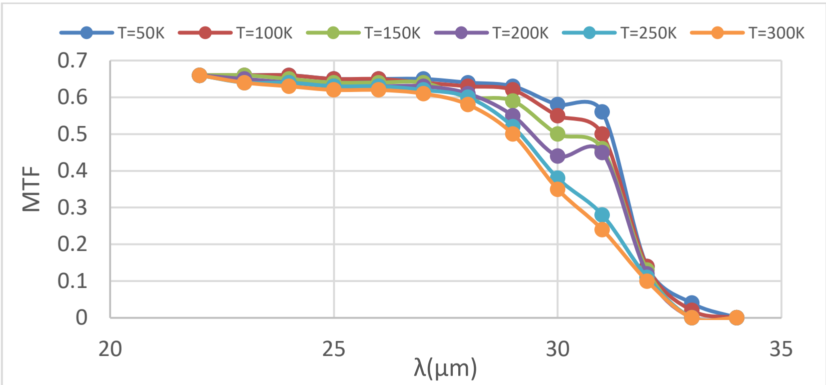


Figure 12: wavelengths versus MTF for different temperatures

3. Conclusion

It has been designed a new model for fractal optical modulator which is consisting of inner circle and outer circle throughout the simulation in visual basic 6.0. The comparison between the values of MTF at different temperature of values, showed that at big values of temperature the value of MTF becoming low (with increasing the temperature, the MTF will decrease), and this means that the detector has low efficiency. The high inflection points for MTF changes with temperature of fractal optical modulator changes. It has been visualized that the values of temperature increase versus the spatial frequency increase, i.e. that fractal optical modulator works good. There is a considerable increase in Modulation Transfer Function (MTF) with decreasing of the spatial frequency. It is very important in the optical fractal modulator, when it is designed from a specific material such special filter. Finally, the best material may be used to make the optical modulator is Cadmium telluride because it must to value large of MTF for range different temperature.

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